Mid-Frequency Reverberation Measurements with Full Companion Environmental Support

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LONG-TERM GOALS:

To understand mid-frequency (1-10 kHz) acoustics in shallow waters through measurements and modeling, including propagation, reflection, and forward- and backscatter, as well as reverberation. The top-level goals of this effort are to understand the important environmental processes that impact mid-frequency sonar performance in shallow water environments, and to develop means to efficiently collect those environmental data.

OBJECTIVES:

The overall goal is to conduct a reverberation measurement in very shallow water off the coast of Panama City, Florida in FY13. This field project is part of TREX (Target and REverberationeXperiment). The frequency range is 1-10 kHz, emphasizing 3-4 kHz. The Navy relevance is reflected in the fact that detection using mid-frequency sonar is in most cases reverberation limited. The proposed work addresses a clear need in basic research for a 6.1 level measurement program,using well-controlled geometries and high resolution environmental measurements, designed to test models predicting reverberation and also toquantify the most important environmental measurements to make in order to maintain accuracy in those predictions. Data from such an experiment can be used for testing various forward and inversion techniques, and can also be used for training purposes.

The water depth of the experiment is in the range of 15-25 m. The relevant water depth for naval applications covers the entire continental shelf. The key issue for reverberation is small grazing angle propagation and scattering in a waveguide. The major burden of such an experiment program is measuring the environment that influences reverberation. Reducing the region over which the environment needs to be measured becomes a primary consideration. By restrictingthe water depth to 15-25 m, the range at which the sound field is dominated by small grazing angle propagation and scattering is shorter than at deeper depths. Therefore, environmental measurements can be limited to a smaller area. Another advantage of working in such water depths is that diver support is

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available, which provides added control of the various measurements. Finally, from an environmental standpoint, the shorter ranges allow lower source levels to be used,and therefore the measurement program can be more easily made compatible with environmental regulations.

Propagation and Scattering mechanisms to be addressed: Bottom roughness (including ripples); water column variability, including internal waves, that affects propagation; surface roughness as a function of wind speed; fish school properties, and known clutter such as ship wreckage.

Supporting Environmental Measurements: Along the propagation path, sediment geo-acoustic parameters to a depth of 2-3 m, emphasizing the top 0.3 m because it has the most effect on long range reverberation; bottom roughness with depth resolution of 1 mm and range resolution of 1 cm; water column sound speed field over time; sea surface roughness as a function of time; and presence of fish schools and their characteristics over time.

APPROACH

This effort is collaboration with PI's funded by ONR OA from many institutions. Collaboratorsfrom APL-UWinclude Brian Hefner, Kevin Williams, and Eric Thorsos, whose work in FY12 is closely related to that reported here.

Instead of using omni-directional transmit and receive transducers, we plan to use the ONR FORA (John Preston, Penn State, POC) as the primary receiver. It has a high-frequency triplet horizontal aperture of 15.6 m, and is cut for a center frequency of 3750 Hz. Its beam width is less than 2 degrees with starboard/portside discrimination. Thus only a 2 degree horizontal wedge ofthe ocean environmentneeds to be measured. A linear 32-element APL array will be used as a secondary receiver.

In April,2012, a pilot test, GulfEx12, was conducted at 20 m depth off Panama City, Florida, with the primary goal of testing all acoustics equipments to be used in TREX13, the main experiment in FY2013. Reverberation data were taken on the two receiving arrays pitched by poles about 2 meters above the bottom. A ping was sent out every two minutes for over 10 hours, so time-dependence (day/night dependence) of reverberation could be examined. The same experimental setup will be used next year in TREX13, when concurrent environmental measurements will be taken.

WORKCOMPLETED

1. Organizational coordination (with Todd Hefner and Kevin Williams) of PI's from multiple institutions involved in TREX13. The first field planning workshop was held in March, 2012. An overall plan has been established, and a day-by-day detailed work plan is in the process of being firmed up, covering logistics and

sound transmission schedules. A second one-day workshop will be held in October, 2012, during the Acoustical Society of America meeting in Kansas, MO.
2. Successful completion of GulfEx12 Pilot Experiment.
3. Data analyzed on reverberation data from the pilot experiment, showing day/night difference on reverberation level. The difference is believed to be due to fish scattering. Steps are taken to take fish scatter into consideration in TREX13.
4. Development of a model to simulate reverberation in shallow water.
5. Development of a hypothesis on the origin of the long-tailed distribution of reverberation intensity.
6. New data analysis result of sediment sound speed at the TREX13 site from the SAMS.
7. Progress on propagation over rough topography and measurement of bottom loss.

RESULTS

1. The main goal of the Pilot Experiment, GulfEx12,wasto test all acoustics measurement systems to be used in TREX13. That goal wasachieved. Reverberation data from that pilot experiment have been partially analyzed. One important observation from the data is that reverberation level increases from day to night about 10 dB. (Fig. 1). The change happens over a short period of time and is believed to be caused by fish migration. As a result, a fish monitoring component will be added to TREX13.
2. A theoretical model was developed (with D. Jackson) to simulate mid-frequency reverberation in range-dependent environments. This model was applied to GulfEx12 data (Fig. 2). The model input used to compare to data were historical values in the experiment area. Real environmental data will be available in TREX13, so direct model/data comparison can be made. The model also predicts a major impact of wind on reverberation (Fig. 3), as work by Thorsos et al. has shown.
3. False alarm rate is a major naval concern. Its existence can often be traced, in a mathematical sense, to the long-tailed distribution in the reverberation intensity PDF. The physical origin was often attributed to patchiness of sediment properties. We have formulated a new hypothesis of the origin of the long-tailed distribution of reverberation intensity: the combination of sea surface forward scatter and bottom backscatter. A straightforward model of the probability density distribution predicts that the combined scattering results in a k-distribution, a well known long-tailed distribution (Fig. 4).
4. Improved estimates of sediment sound speed in the TREX13 area from data taken by the SAMS system. (Fig. 5). In the frequency band of 3 – 7 kHz, sound speed was found in the range of 1675 ± 20 m/s.
5. Impact of fine scale topography on bottom loss measurement. Bottom Loss (BL) is one of the parameters in data bases. In measurements, the bottom is assumed flat. However, the effect of gentle variation of bottom topography has not been examined. The TREX site is considered nominally flat. Multibeam survey by Christian de Moustier provided fine scale bottom topography data during GulfEx11. Modeling of BLbased on the real topography indicates that there is up

to 5 dB fluctuation of BL around the flat bottom model at small grazing angles. It is found to be due entirely to focusing effect by the bottom curvature. Concurrent BL and bottom topography measurements are planned for TREX13.

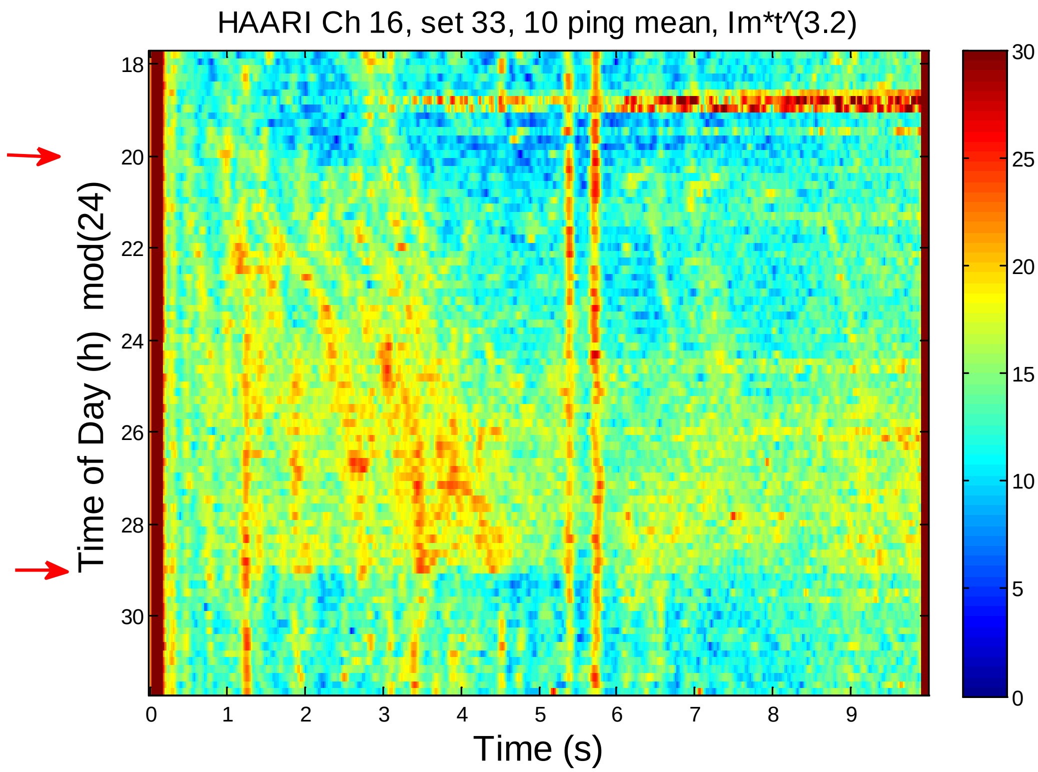

Figure 1 Normalized reverberation intensity from GulfEx12. The vertical axis is time of day, ranging from 6 pm to 7 am the following day. An increase in intensity of about 10 dB is observed first at dusk, then a comparable decrease at dawn. (Dusk and dawn are indicated by arrows on the figure)

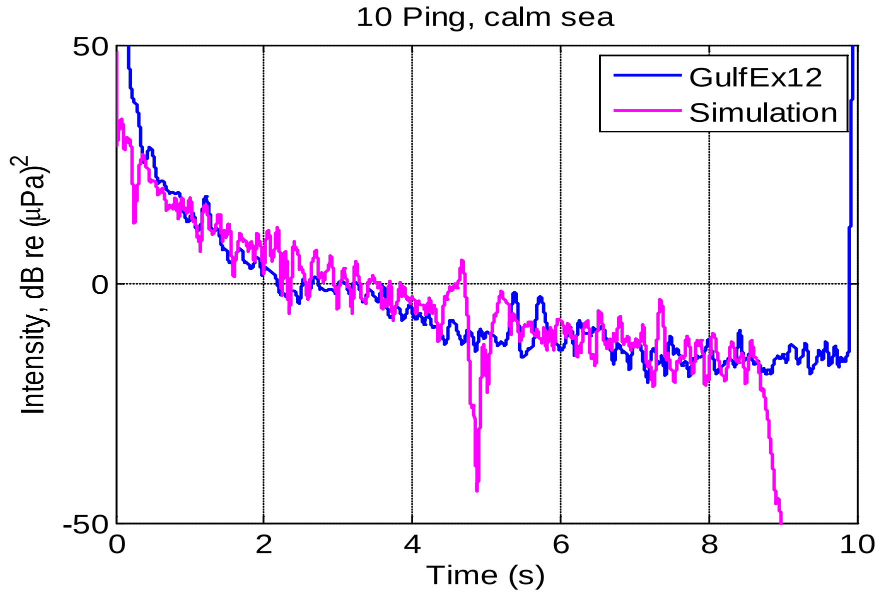

Figure 2.Model/data comparison of reverberation intensity on single channel from GulfEx12.The model assumes bottom roughness scattering and model inputs are estimated values based on SAX99 data. Wind speed is assumed 0 m/s.

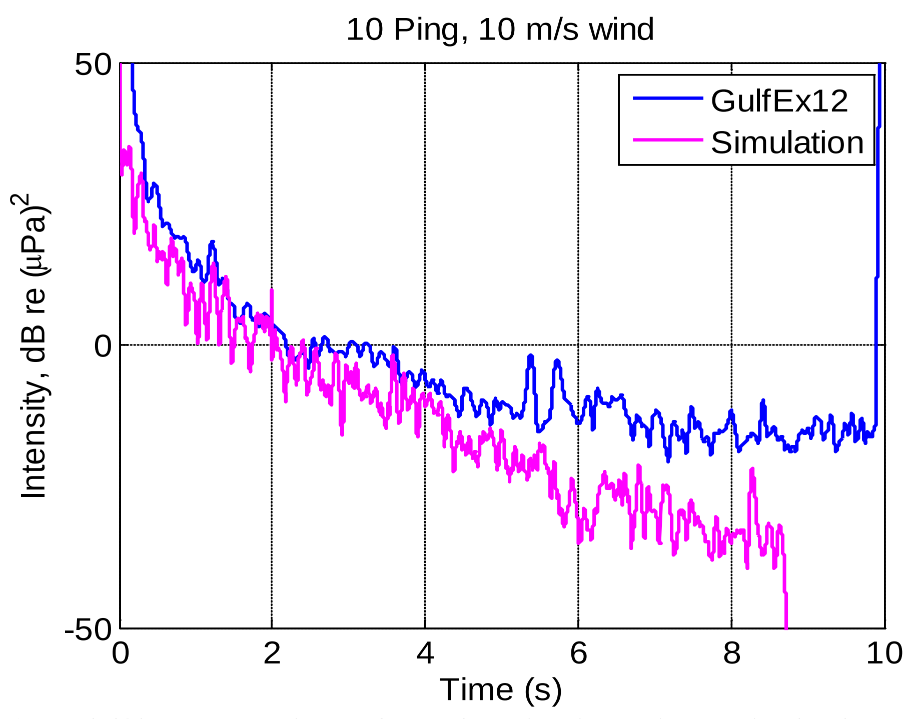

Figure 3.Model/data comparison of reverberation intensity on single channel from GulfEx12. All parameters to model are the same as in Figure 2, except wind speed is assumed 7.7 m/s. The wind causes the sea surface to forward scatter sound, and part of the forward scattered sound into high grazing angles is lost to the sediment.

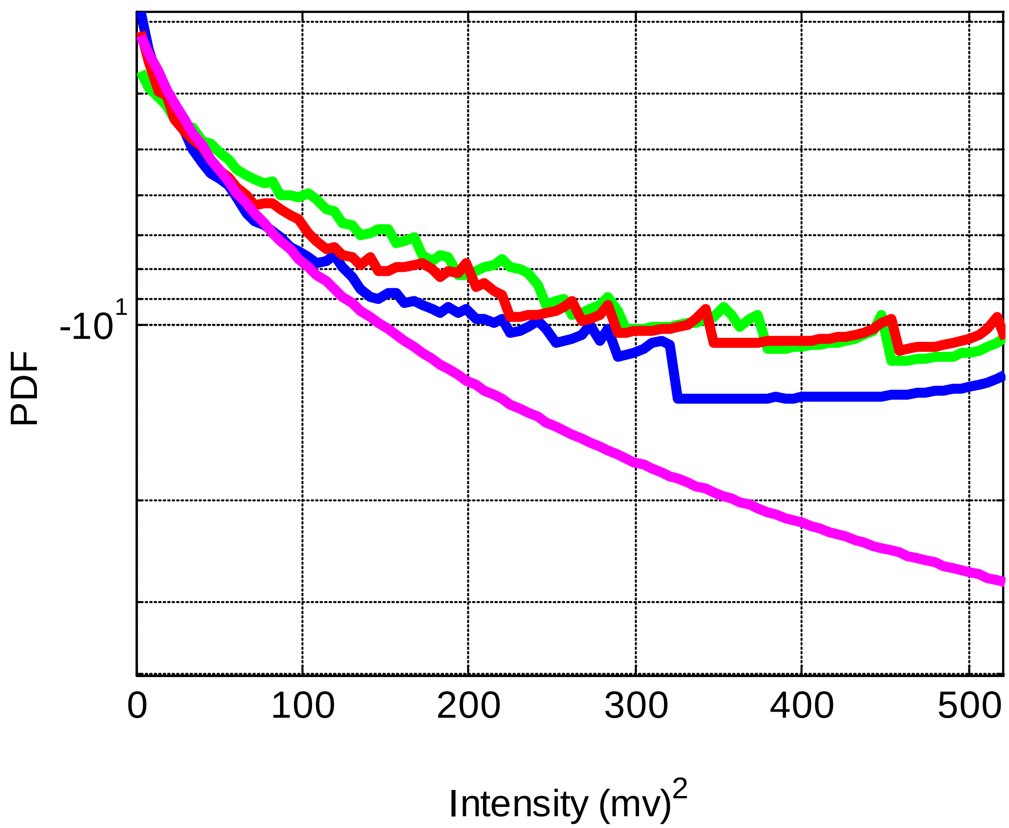

Figure 4.Measured PDF from GulfEx12 data (rough curves) as compared to the exponential PDF (pink smooth curve). A theoretical k-distribution PDF compares favorably to data. The theory is based on the hypothesis that reverberation is a combined sea surface forward scatter and bottom backscatter. Quantitative proof will be sought as part of TREX.

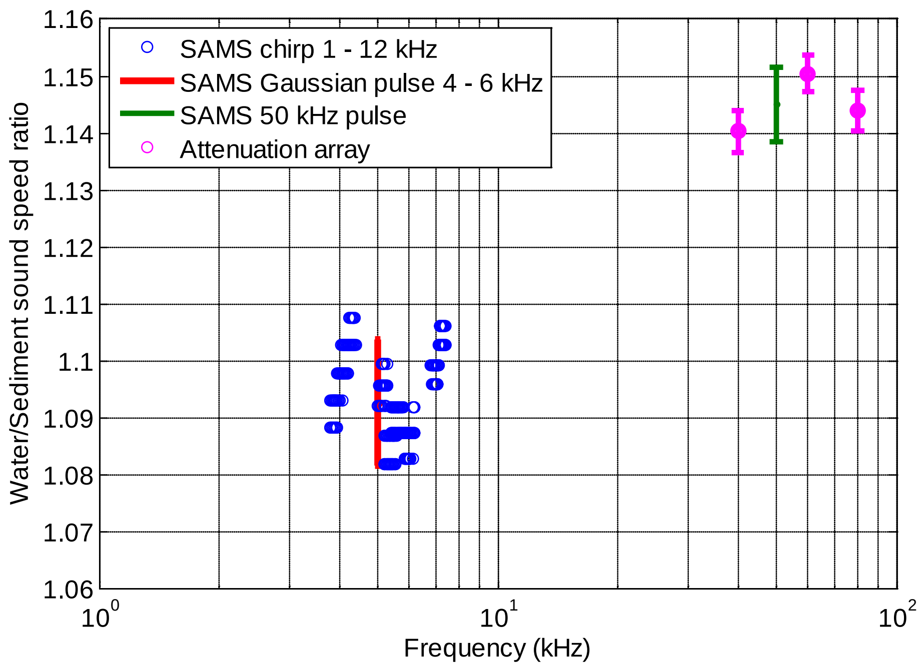

Figure 5.Comparison of sediment sound ratio from in situ measurements made during GulfEx11 – GulfEx12. Two instruments were used: one is SAMS and the other is the attenuation array (results from Brian T. Hefner) For both, sediment/water sound speed ratio was obtained by comparing the arrival times betweenin-sediment and in-water data.

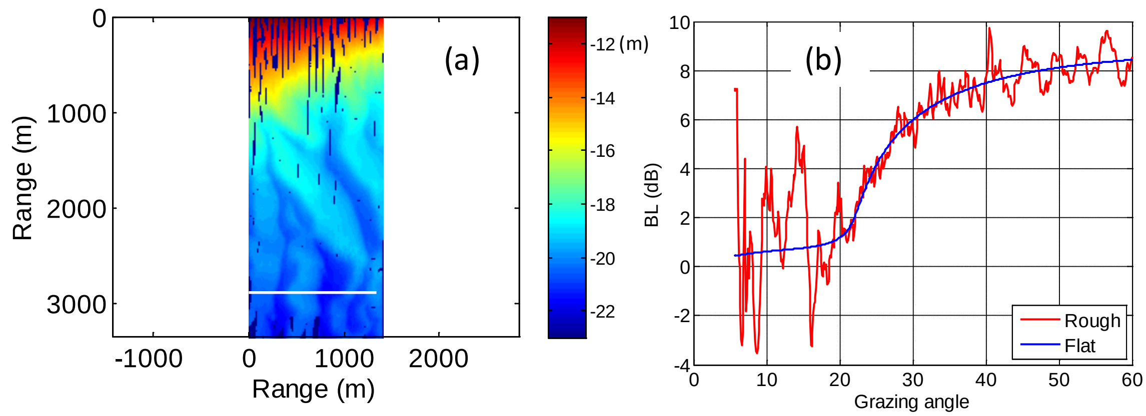

Fig. 6.Effects of gently varying topography on bottom loss at mid-frequencies.(a) fine-scale topography data taken by Chris deMoustier during GulfEx11; (b) prediction of bottom loss at 3.5 kHz for flat and rough bottoms. Rough bottom uses the bathymetry trace highlighted in white in (a).

IMPACT/APPLICATIONS

Naval active sonar detection is often reverberation limited. Understanding the main mechanisms that cause the diffuse reverberation willlead to better sonar performance.Theoretical and numerical progress inspired by the field work will find applications toward detection in shallow water areasincluding operational recommendations of the most important environmental measurements to make in order to maintain accuracy in predictions of reverberation.

RELATED PROJECTS

NAVOCEANO data bases

ONR Signal processing code, active

“High Fidelity Finite Element Modeling for the Identification of Low- to Mid-Frequency Proud and Buried Object Elastic Responses and SAS Image Features,” ONR Grant #: N62909-10-1-7153, PI: M. Zampolli

“Reverberation, sediment acoustics, and targets-in-the-environment,” ONR Grant #: N00014-11-1-0428, PI: K. L. Williams.

“Full Scale Measurement and Modeling of the Acoustic Response of Proud and Buried Munitions at Frequencies from 1-30 kHz,” SERDP Contract #: W912HQ-09-C-0027, PI: S. G. Kargl

PUBLICATIONS

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2. Jie Yang, Darrell R. Jackson, and Dajun Tang, “Mid-frequency geoacoustic inversion using bottom loss data from the Shallow Water 2006 Experiment”, J. Acoust. Soc. Am. **131 (2)**, 1711- 1721 (2012).
3. Tang, D., and B. T. Hefner, “Modeling backscatter from a series of sediment rough interfaces by a normal incident chirp sonar,”J. Acoust. Soc. Am., **131**, EL302-308 (2012)
4. Tang, D., F.S. Henyey, D. Rouseff, and J. Yang, “Single-path mid-frequency acoustic intensity fluctuations in shallow water, ”J. Acoust. Soc. Am., (In preparation).
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6. Yang, J., D. Rouseff, D. Tang, and F. S. Henyey, "Effect of the internal tide on acoustic transmission loss at mid-frequencies", *IEEE J. Oceanic Engineering,* Vol. 35, 3-11 (2010).